

# Supply Noise Effect on Oscillator Phase Noise

*Habeeb Ur Rahman Mohammed, Ph.D.*
*High Speed Products*

## ABSTRACT

This report provides the description of local oscillator (LO) phase noise degradation due to supply noise. Brief theoretical information supported by experiments carried out to demonstrate this degradation is discussed. The importance of selecting appropriate low-noise LDO (low-dropout) linear regulators is discussed. The impact of improper LDO within in-band phase noise of a multi-GHz synthesizer is shown to be more than 15 dB. Texas Instruments TRF3765 low-noise synthesizer and TPS717xx and TPS742xx LDOs are used in this analysis. The significance of using linear laboratory supply over digital switching supply for optimum phase noise is illustrated.

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## 1 Introduction

Wireless transceivers require RF oscillators that must meet strict requirement of low phase noise. If the oscillator phase noise is degraded, then both down-converted and up-converted signals are corrupted. Many factors degrade oscillators phase noise performance, and one among them is supply noise. This application report provides brief explanation of phase noise degradation due to supply noise.

Phase noise at the local oscillator (LO) output is effected by supply noise mostly due to the following two significant reasons.

### 1.1 Ringing at $V_{CC}$ Due to Change in Current Drawn by LO

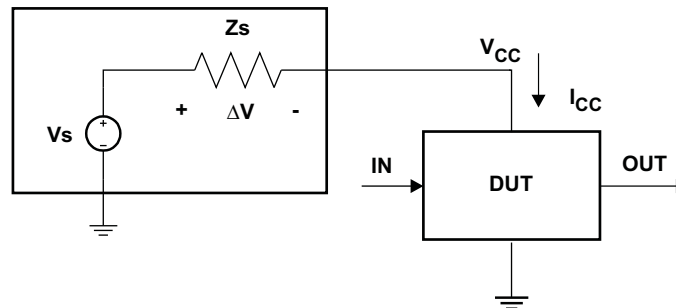


Figure 1. Simple Setup With LO (DUT) and Supply

Figure 1 shows a simple block diagram with the LO, the device under test, (DUT) supplied by the  $V_{CC}$  and  $I_{CC}$ . The supply is considered to have source voltage,  $V_s$ , and source impedance,  $Z_s$ . This supply can either be considered as a laboratory supply or laboratory supplies + LDO. In an ideal case,  $Z_s = 0$ ; however, in a non-ideal world,  $Z_s \neq 0$ .

With the activity of LO, the supply current  $I_{CC}$  changes, and this changes the drop across  $Z_s$ , i.e.,  $\Delta V$ , this translates to change in the supply  $V_{CC}$  and is added as noise to LO phase noise. This noise can be minimized by using supplies with minimum  $Z_s$ , or the LDOs used must be robust against the changes in  $I_{CC}$ . Essentially, it is desirable that the ac output impedance be as low as possible. Most of the TI LDOs has low output impedance (and usually decoupling capacitors are added to minimize the ac output impedance), and thus the phase noise affected due to  $V_{CC}$  ringing is less. Change in the synthesizer frequency due to change in  $V_{CC}$  is termed as *VCO (voltage controlled oscillator) pushing*.

### 1.2 Noise Generated by LDO

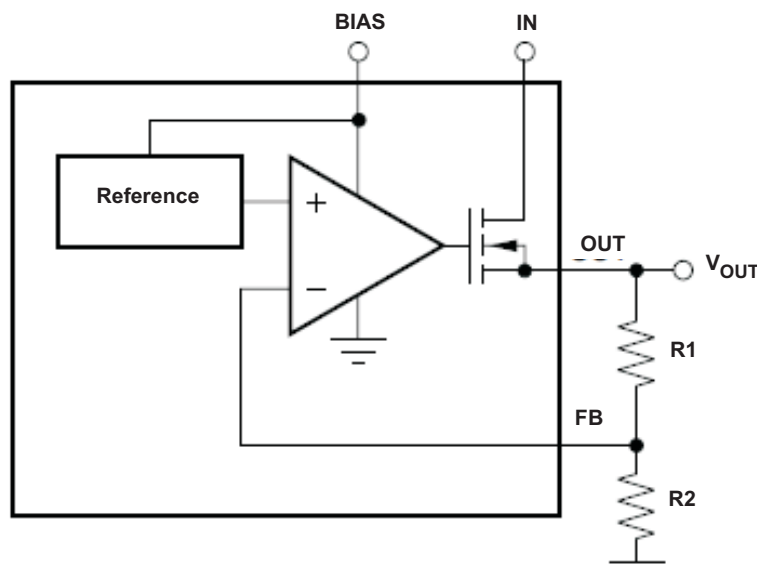


Figure 2. Simplified LDO Block Diagram

Figure 2 shows the simplified LDO block diagram. The LDO output is regulated with respect to the LDO band gap reference. Any noise on the LDO band-gap reference is translated at the LDO output. Considering the noise power generated at the band gap reference  $[V_{nBG}]^2$ , the noise power at the output from the band gap reference  $[V_{nBGout}]^2$  is as is given in Equation 1:

$$[V_{nBGout}]^2 = \left[1 + \frac{R1}{R2}\right]^2 \times [V_{nBG}]^2 \quad (1)$$

Along with the LDO band-gap reference, total output referred noise at the LDO output is the sum of noise generated by the error amplifier, noise from the pass transistor, and thermal or 4KTR noise from the R1 and R2 resistor divider network. Noise from LDO band-gap reference is usually the dominant source.

This application report illustrates the importance of this noise, which effects LO phase noise. The following discussion describes how the LDO with higher output noise spectral density degrades the LO phase noise to a great extent.

## 2 Theoretical Background Information

Ideally, a voltage-controlled oscillator has its output frequency linearly related to its controlled voltage as:

$$f_{out} = K_{VCO} \times V_{control} \quad (2)$$

Here,  $f_{out}$  represents output frequency,  $V_{control}$  is the control input voltage which tunes the output frequency, and  $K_{VCO}$  is gain of the oscillator.  $K_{VCO}$  is represented in Hz/V, and it is assumed that output frequency at zero control voltage is zero.

Constant control voltage leads to perfectly periodic output oscillations. The noise on the supply couples through PSRR (power supply rejection ratio) and  $K_{VCO}$  to output and degrades due to phase noise performance of VCO.

## 3 Experimental Evaluation of Phase Noise Degradation With Supply Noise

This section describes an experiment performed to evaluate and understand the degradation in phase noise at oscillator output due to supply noise.

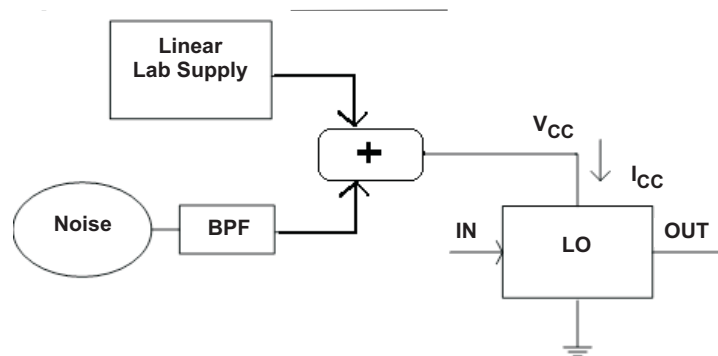
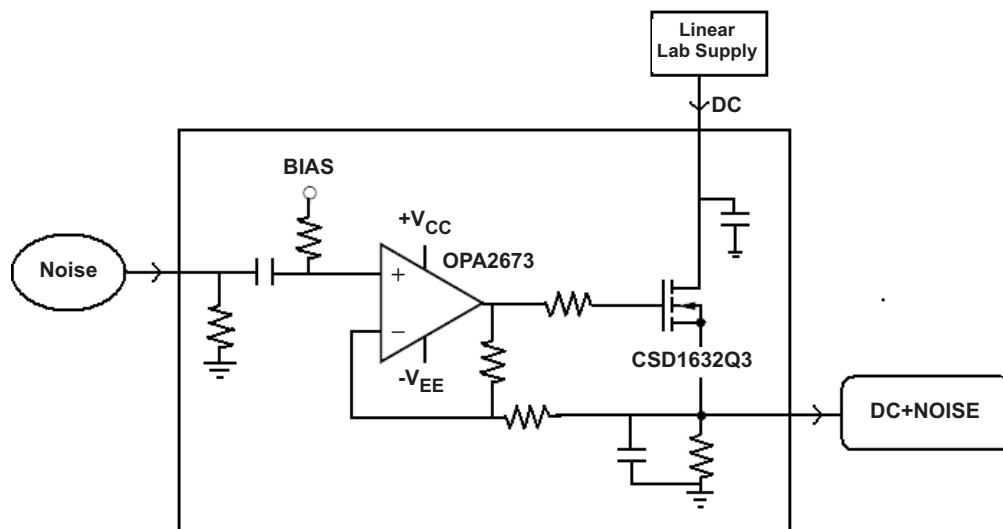


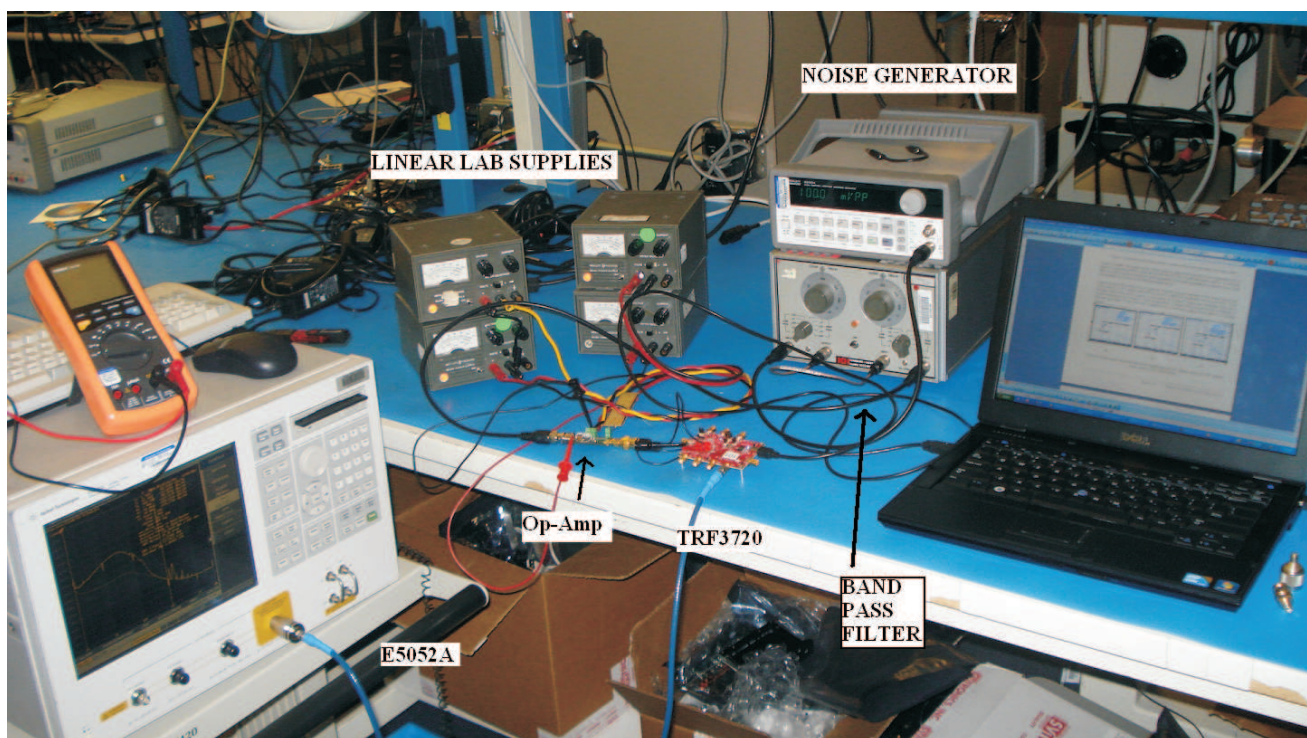
Figure 3. Experimental Setup Block Diagram to Observe Phase Noise Degradation With Supply Noise

Figure 3 shows the block diagram of an experimental setup where AWGN (additive white Gaussian noise) is injected at the supply. A band-pass filter is used to control noise bandwidth such that degradation in phase noise can be observed according to the amount of band-limited noise added to the supply. Also, the amplitude of noise is varied to quantize the amount of phase noise degradation with respect to noise amplitude on supply.

To obtain a noisy dc supply, noise from a function generator is added to the linear dc supply using a negative feedback operational-amplifier circuit shown in Figure 4.



**Figure 4. Operational-Amplifier Circuit Used to Add dc and Noise**



**Figure 5. Experimental Setup**

Noise level and noise bandwidth at the input of the operational amplifier is varied to obtain a fixed amount of noise (+DC) at the output of operational amplifier to drive the oscillator. The TRF3720 in integer mode is used for this analysis. Figure 5 shows the picture of the experimental setup. Following is the list of equipment used in the experiment:

- Noise generator: HP 33120A, 15-MHz function/arbitrary waveform generator.
- Filter: KROHN-Hite 3202 band-pass filter.
- Analog supplies: HP6216A.
- Digital switching supply: HP E3631A triple-output dc power supply.



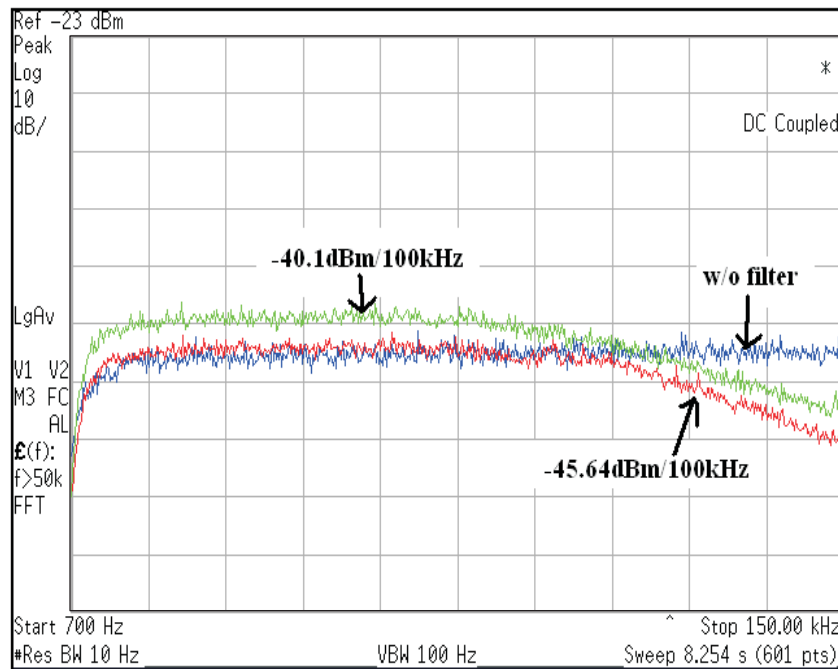
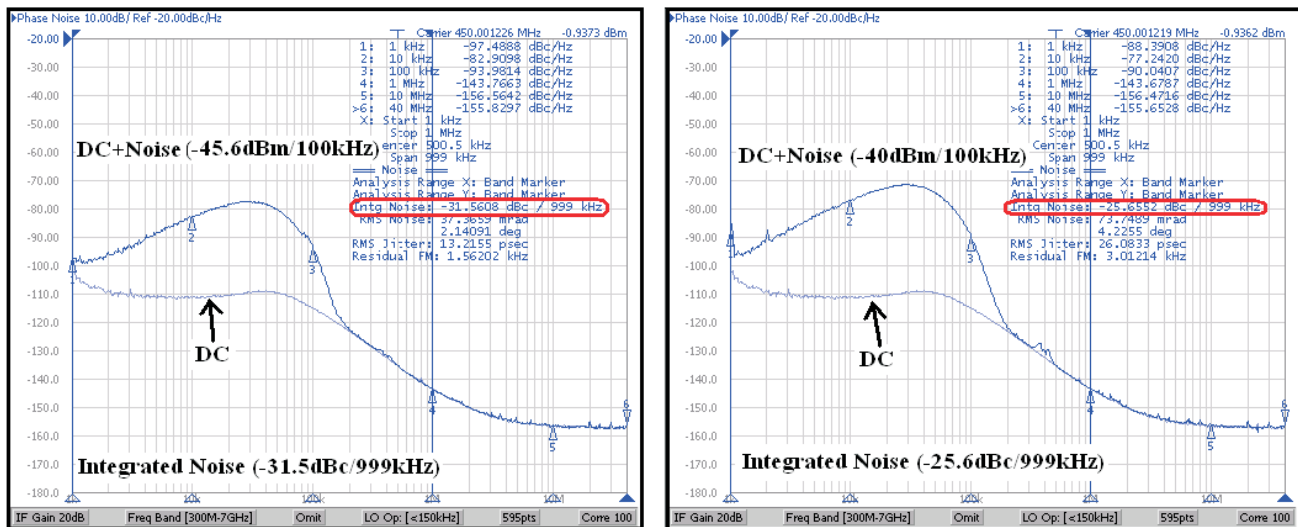


Figure 7. Spectrum of Filtered and Unfiltered Noise Added to dc Supply



(a) Linear DC supply + Noise with channel power -45.6dBm/100 kHz from 1 kHz to 100 kHz

(b) Linear DC supply + Noise with channel power -40.6dBm/100 kHz from 1 kHz to 100 kHz

Figure 8. Phase Noise Response With Linear dc Supply

### 3.2 Phase Noise Degradation With Supply Noise Bandwidth

In this experiment, the level of the noise is kept constant and the band-pass filter bandwidth is varied between 9 kHz to 99 kHz, more specifically from 1 kHz to 10 kHz and from 1 kHz to 100 kHz, respectively. Figure 9 shows the noise power at the supply, specifically the output of the operational amplifier. Figure 9(a) and Figure 9(b) show the integrated noise power of  $-55.82$  dBm/10 kHz and  $-40.09$  dBm/100 kHz obtained by setting at fixed noise level within the function generator and varying band-pass filter bandwidth. The difference in noise power in both cases is 15.73 dB.

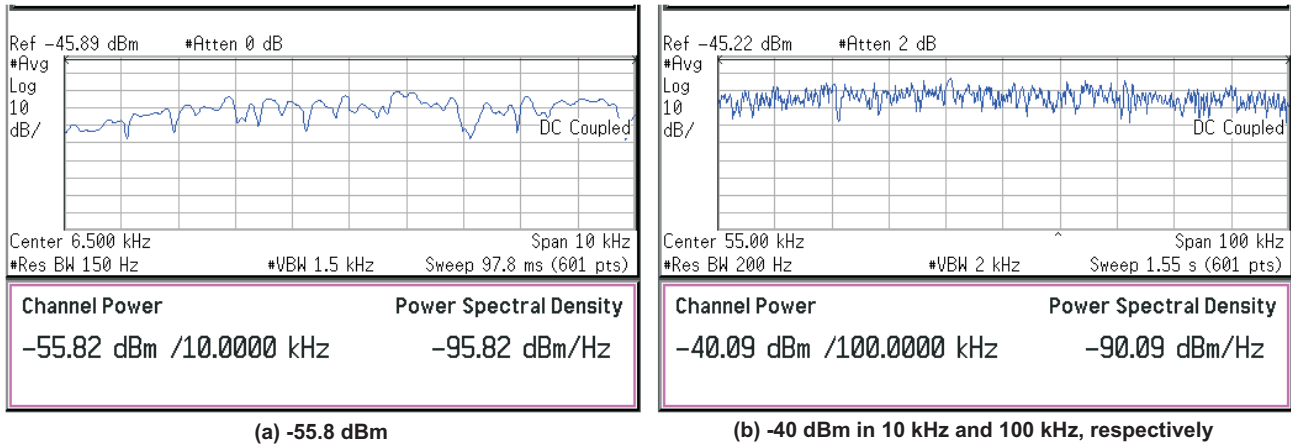


Figure 9. Noise Power Added to Linear dc Supply

Figure 10 shows the time domain response in these two cases, i.e., 9-kHz and 99-kHz band-filtered noise signals added to dc.

Figure 11 shows the phase noise response of the linear supply compared to the phase noise with noisy supply. As expected, more degradation is observed when an increased noise bandwidth is added to the supply. The integrated phase degraded by increasing the noise from  $-55.82 \text{ dBm}/10 \text{ kHz}$  to  $-40.09 \text{ dBm}/100 \text{ kHz}$  is  $-41.49 \text{ dBc}/999 \text{ kHz}$  and  $-25.65 \text{ dBc}/999 \text{ kHz}$ , which is a difference of about 15.84 dB. This is similar to the difference in the amount of noise injected at the supply and is 15.73 dB. Thus, from these two experiments it is clear that supply noise effects LO phase noise.

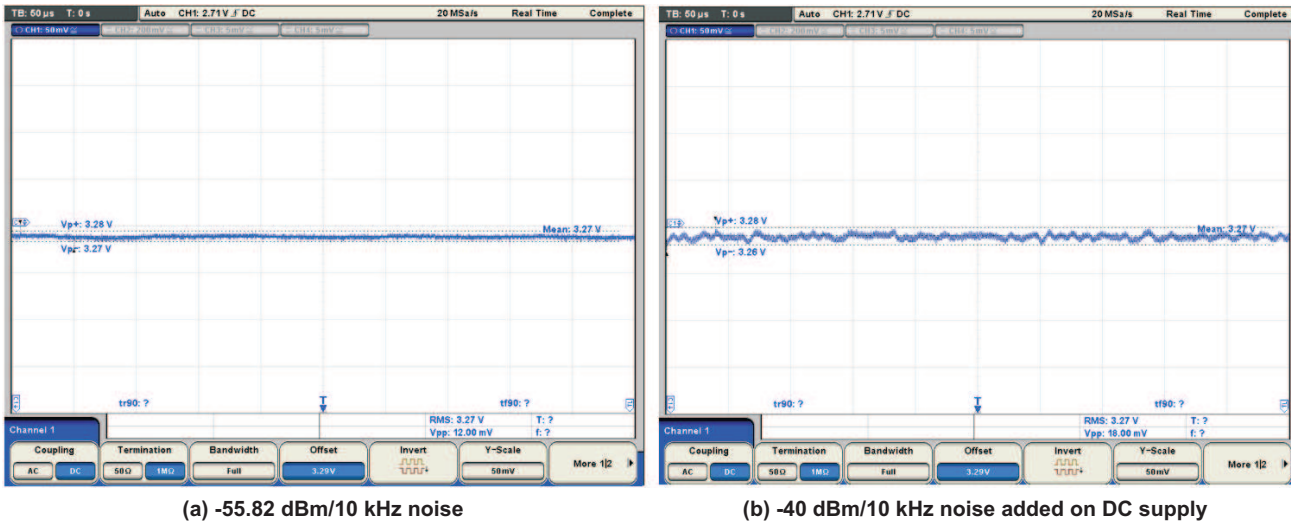


Figure 10. Time Domain Response

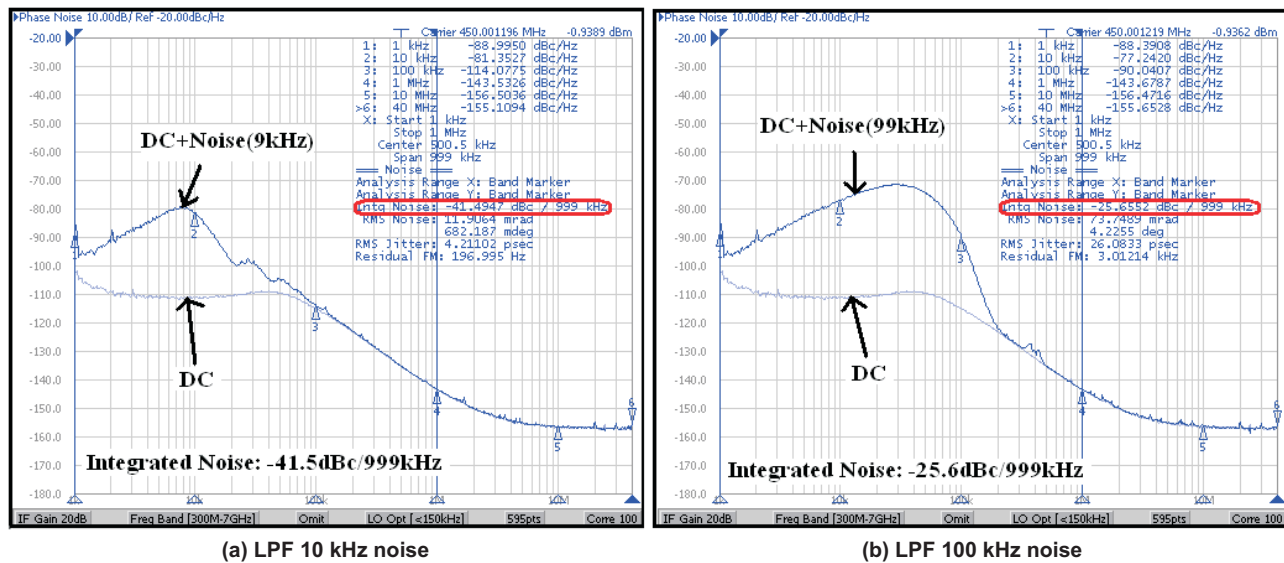


Figure 11. Phase Noise Response With Linear Supply

#### 4 Significance of LDO Low-Noise Spectral Density

This section illustrates the importance of using LDOs with low-noise spectral density for oscillator phase noise. To evaluate this Texas Instruments low-noise wideband synthesizer TRF3765 and LDOs TPS742xx and TPS717xx were considered. TPS717xx is an ultrahigh PSRR (power supply rejection ratio) linear regulator; however, TPS742xx has better output noise spectral performance as shown in Figure 12.

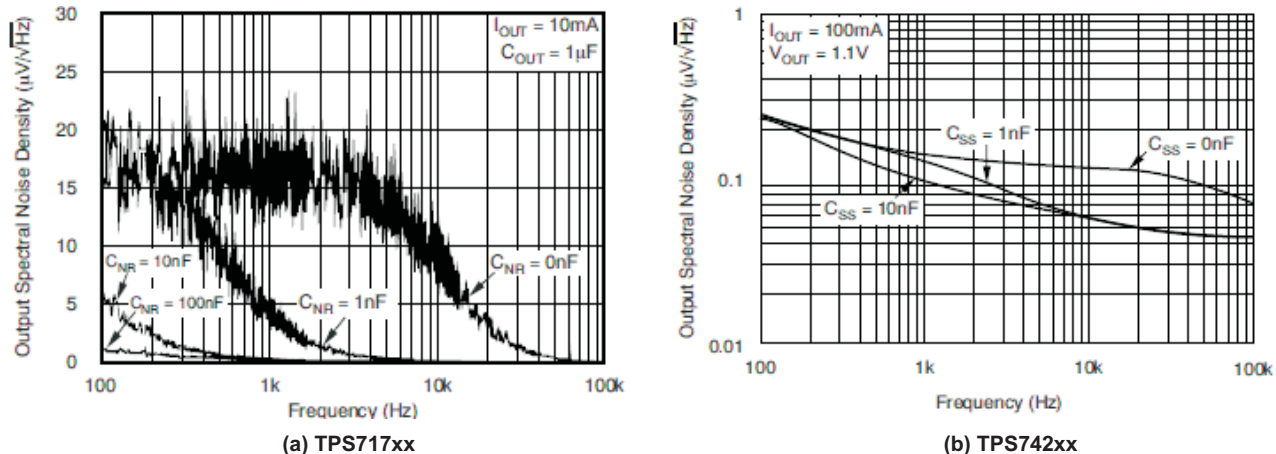
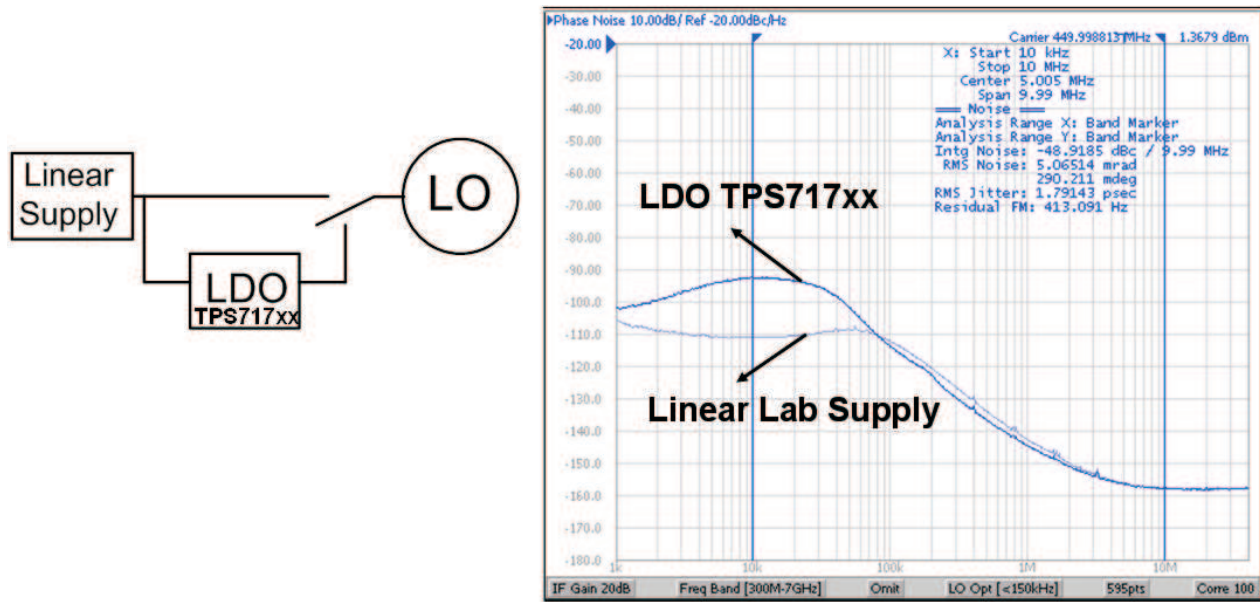


Figure 12. Output Spectral Noise Density

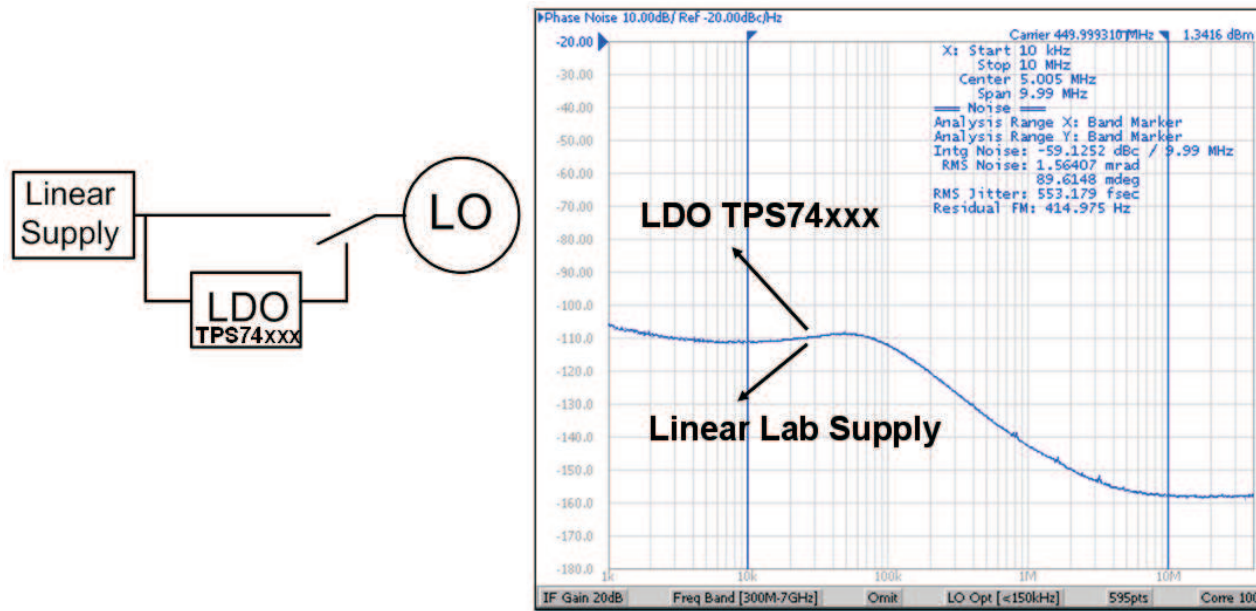
Figure 12(a) is output spectral noise density of TPS717xx LDO and is represented as Figure 26 in its data sheet. Figure 12(b) is output spectral noise density of TPS742xx and is Figure 16 of its data sheet. These plots are for different output parameters. However, by looking at the curves it can be estimated that for the same output regulated voltage, TPS742xx consists of lower output spectral noise power. Phase noise of TRF3765 from linear laboratory supply is compared with the phase noise from these LDOs.

Figure 13(a) shows the phase noise response of TRF3765 using a linear laboratory supply and TPS717xx LDO, and it can be observed that phase noise performance is degraded with the TPS717xx. In band noise, the TPS717xx is more than 15 dB higher. However, using the TPS74xx, LDO phase noise performance is the same as that of a clean linear laboratory supply and can be seen in Figure 13(b). The degradation in phase noise using TPS717xx LDO is due to its higher output noise, which was translated at the output of the synthesizer.





(a) TPS717xx



(b) TPS742xx

Figure 13. TRF3765 Phase Noise Using Linear Laboratory Supply

## 5 Phase Noise Response With Clean Linear and Digital Switching Laboratory Supplies

Switching digital laboratory supply also tends to degrade the in-band phase noise performance, and is illustrated in this section. Figure 14 shows the picture of the experimental setup with a linear and switching supply. Figure 15 shows a phase noise response of TRF3765 using linear and switching laboratory supplies and degraded phase noise with switching laboratory supply can be seen.

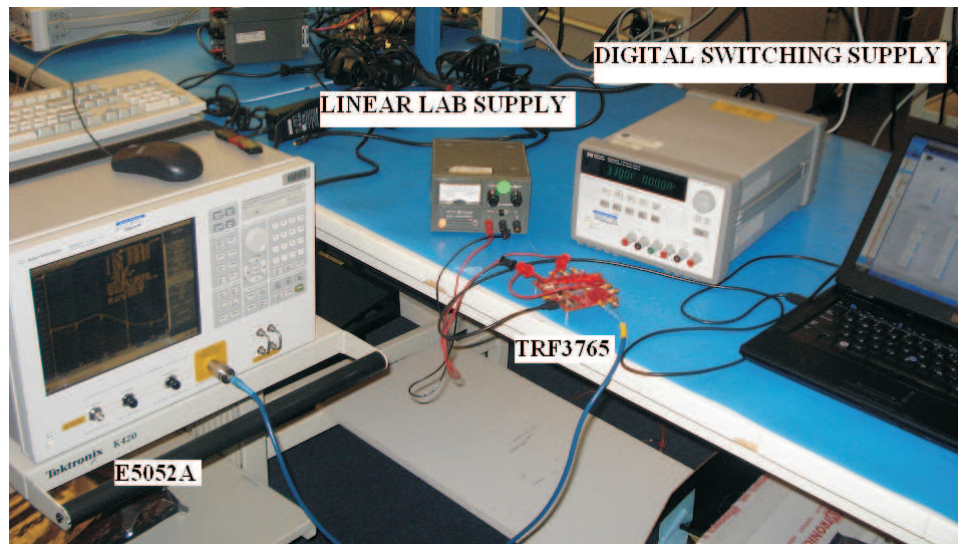


Figure 14. Experimental Setup With Linear and Switching Supplies

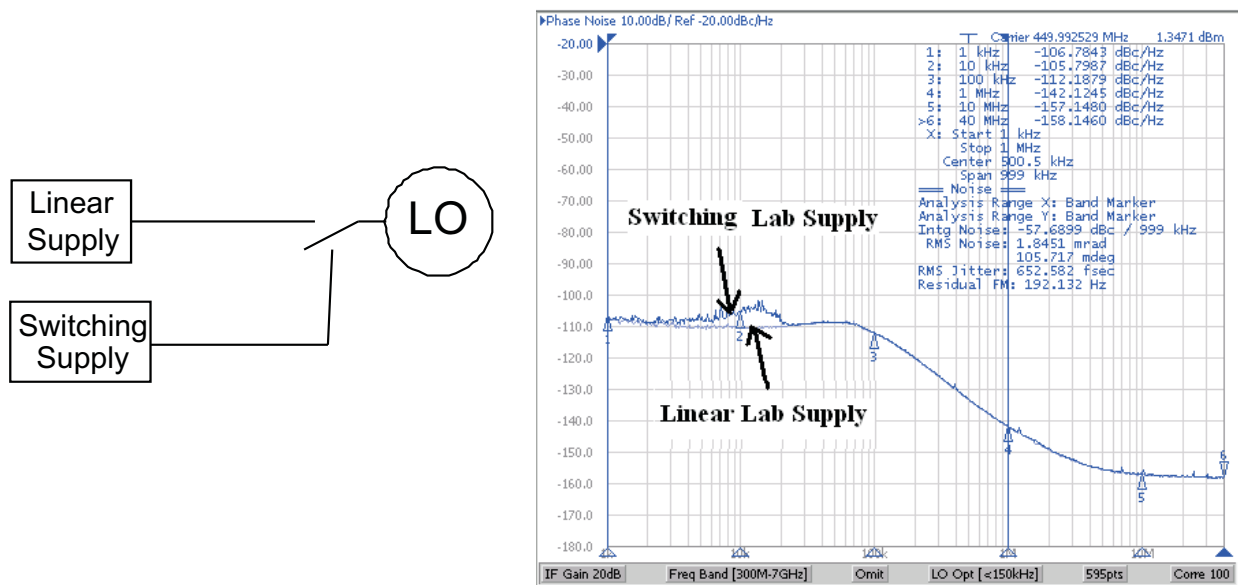


Figure 15. TRF3765 Phase Noise Response Using Switching and Linear Laboratory Supplies

## 6 Summary

This application report provides a brief overview along with experiments on the degradation of the oscillator phase noise with the supply noise. The document demonstrates the significance of using LDO linear regulators with less output spectral noise for optimum phase noise performance of synthesizers. The data herein show the importance of using linear laboratory supplies over switching digital laboratory supplies in phase noise measurement.

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